



# End-to-end System level M&S tool for Underbody Blast Events

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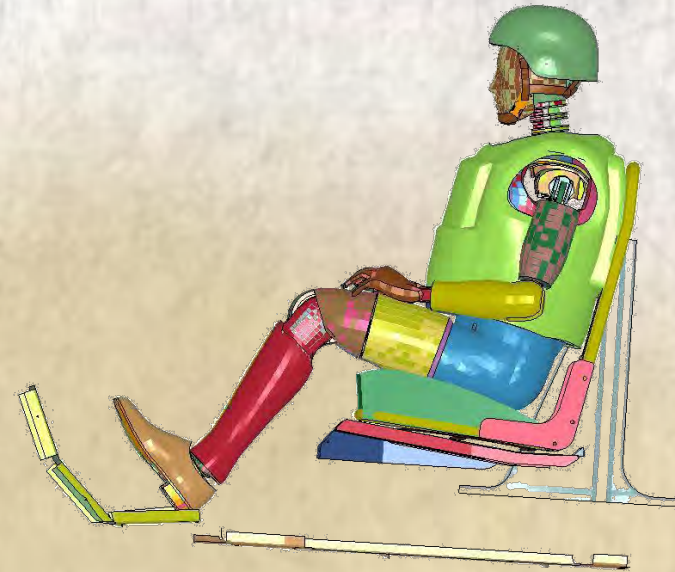
**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

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Engineering Center (TARDEC), Warren, MI**

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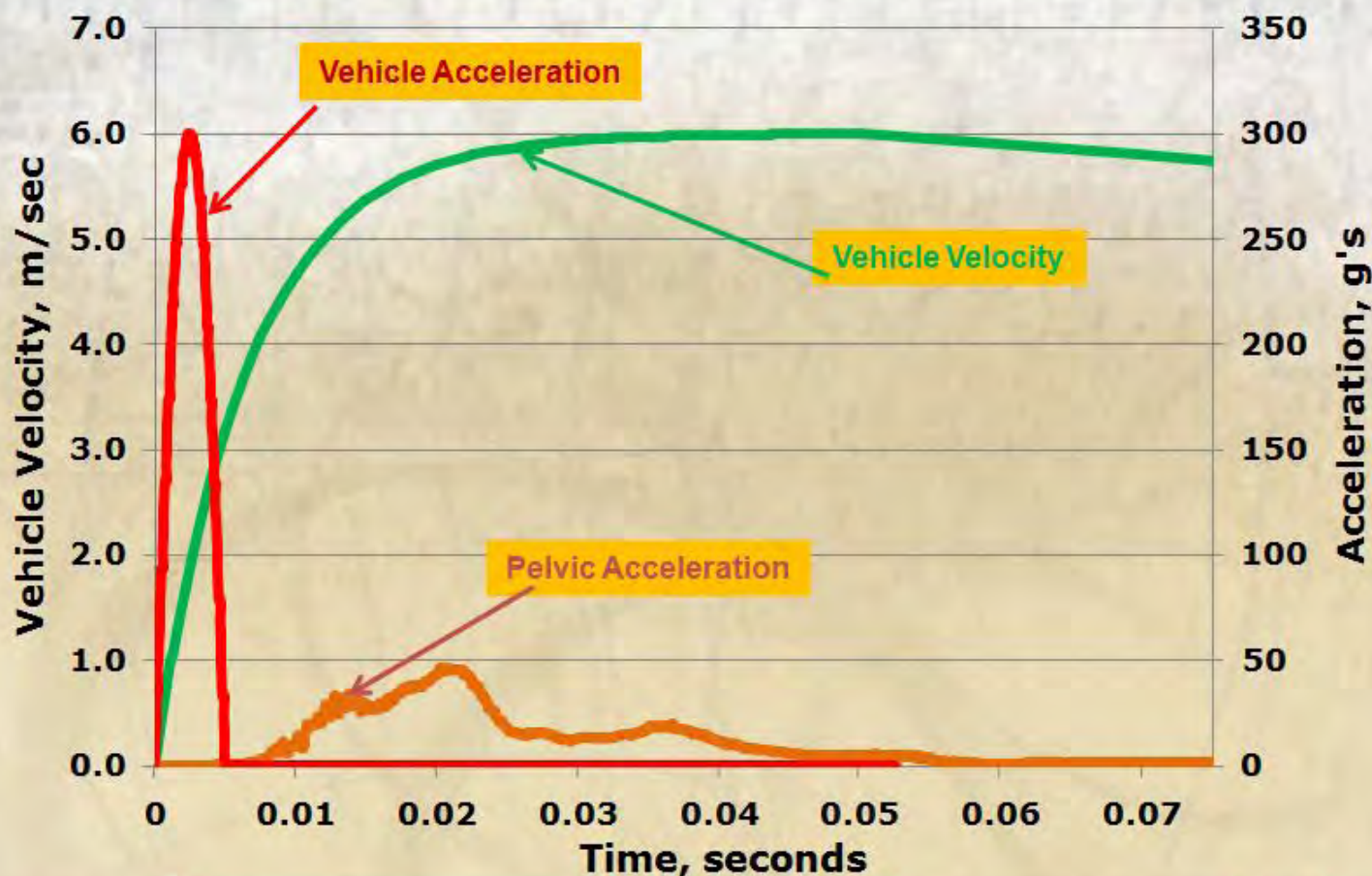
# Underbody Blast Event



High speed event	Typical Peak accelerations	Typical Time Duration Range (ms)
Frontal Automotive Crash (30-mph)	25 g to 50 g	70 ms to 120 ms
Underbody Blast	100 g to 400 g	3 ms to 30 ms (primary)

**Peak Accelerations in underbody blast events are larger in magnitude and sooner than in typical automotive crash events**

# Underbody Blast Event Sequence

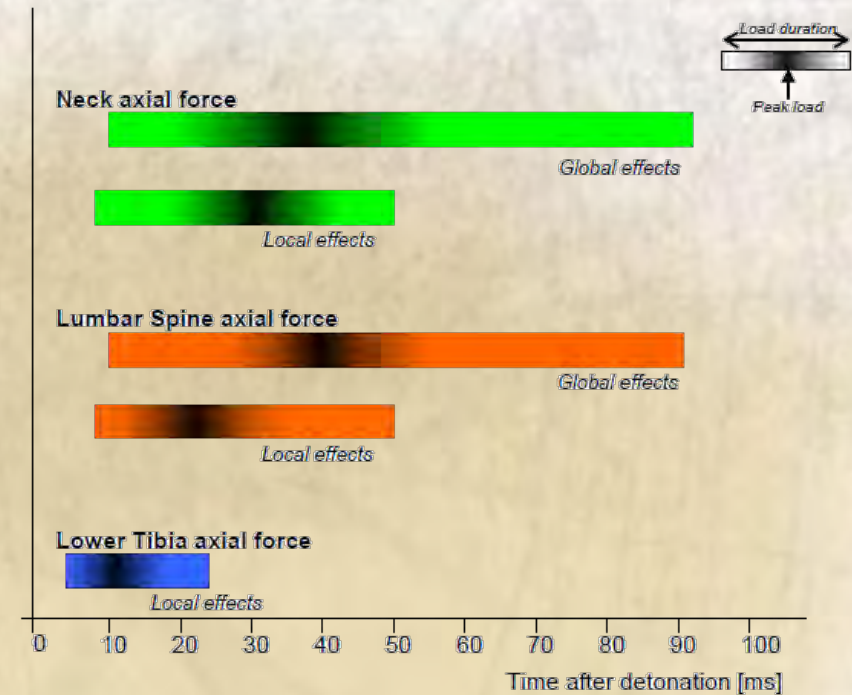
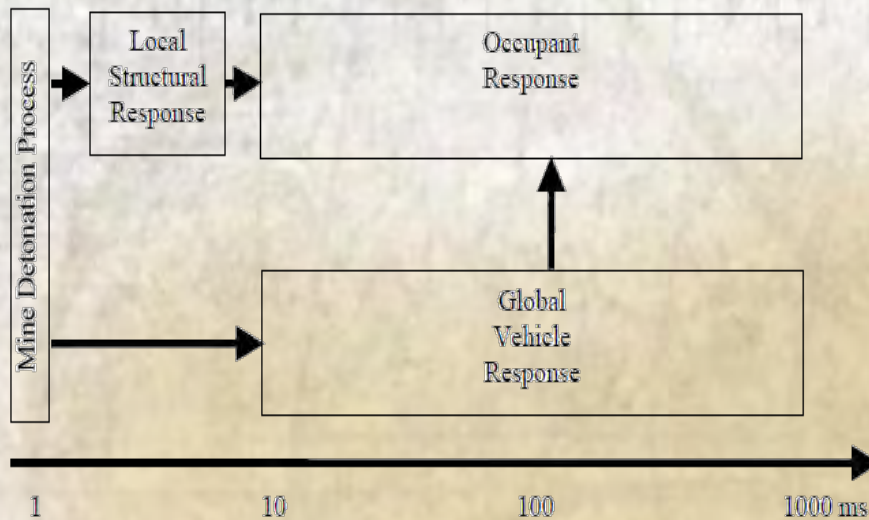


- ✓ Blast phase, lasts ~0.050 s
- ✓ Vehicle velocity builds up to constant peak value
- ✓ All key occupant injuries occur in this phase

- ✓ Gravity phase, lasts 1-2 s
- ✓ Vehicle Velocity reduces due to gravity, reaches peak upward displacement (liftoff), then drops down due to gravity (slam-down)



# Underbody Blast Event Sequence



Source: NATO Research and Technology Organization Technical Report TR-HFM-090

**Injuries in lower legs occur due to local structural effects in the first 10-15 msec, while Core spinal injuries occur due to global vehicle effects in the next 50 msec**

# Spinal Injuries from IED attacks



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## Spinal injuries up among troops

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By Dima Gavrysh, AP

A U.S. soldier unloads 50-caliber rounds from an MRAP vehicle after an IED attack in Wardak province on Aug. 3 in Afghanistan.

By Gregg Zoroya, USA TODAY

BAGRAM, Afghanistan — Afghan insurgents are using roadside bombs powerful enough to throw the military's new 14-ton, blast-resistant vehicles into the air, increasing broken-back injuries among U.S. troops.

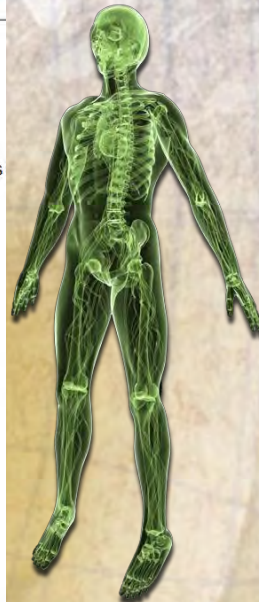
Doctors at the U.S. military hospital here say more than 100 U.S. servicemembers have suffered crushed or damaged spinal columns from being thrown around inside armored Mine Resistant Ambush Protected (MRAP) vehicles in the last five months.

**TROOP DEATHS:** [American casualties in Afghanistan, Iraq and beyond](#)

This "significant increase" in spinal injuries was not seen in the Iraq war, says Air Force Col. Warren Dorlac, director of trauma care for both conflicts. One in five wounded service members evacuated from Afghanistan this summer and early fall suffered a spinal injury and at least 14 were left paralyzed or with loss of sensation, says Air Force Lt. Col. Dustin Zierold, a surgeon and the hospital's director of trauma care.

"Whatever the G-force (of the roadside bombs), it is very high and very destructive," Zierold says.

■ **TROOPS AT RISK**



**Spinal injuries, which are on the rise in theater, correlate to higher number of IED attacks on ground vehicles**



# Injury Criteria

## Injury Assessment Tools

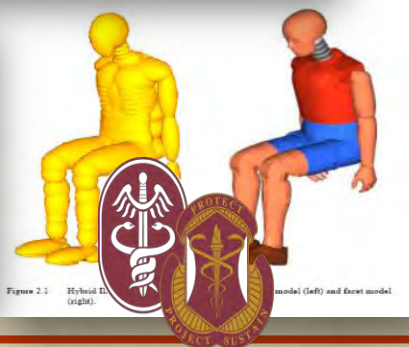
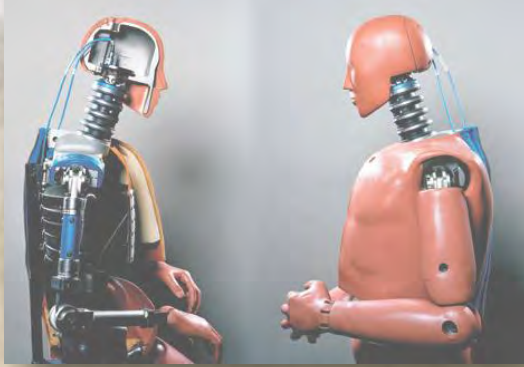
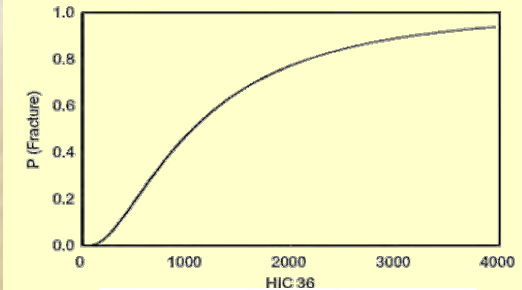
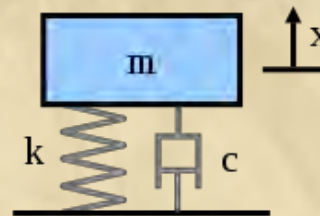


Figure 2.1 Hybrid III (right) and FEM (left) models

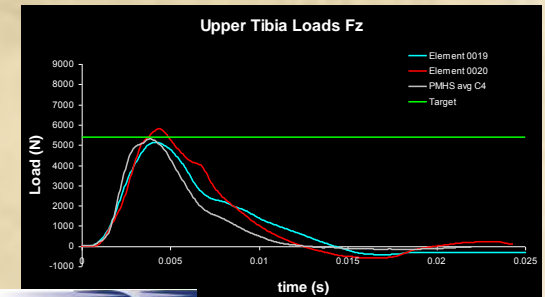
## Injury Criteria



### Lumped Parameter Spine Model (DRI-Z)



$$HIC = \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right]^{2.5} (t_2 - t_1)$$



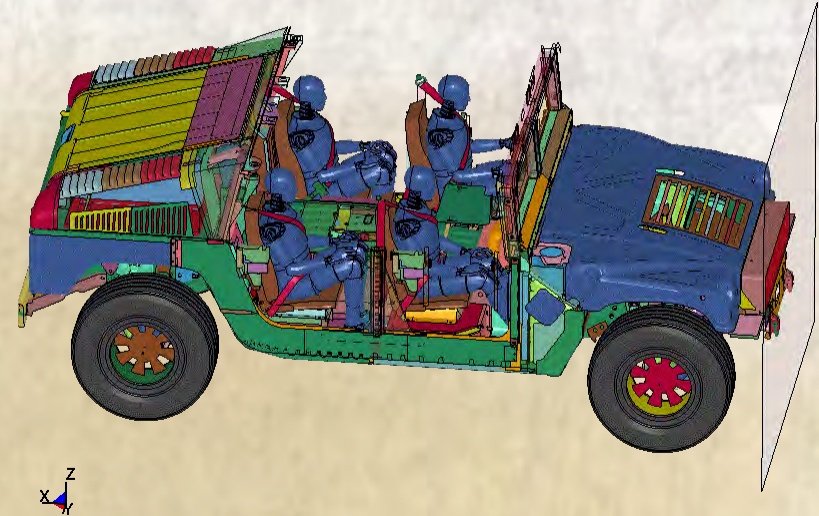
USMRMC

nhtsa "People Saving People"



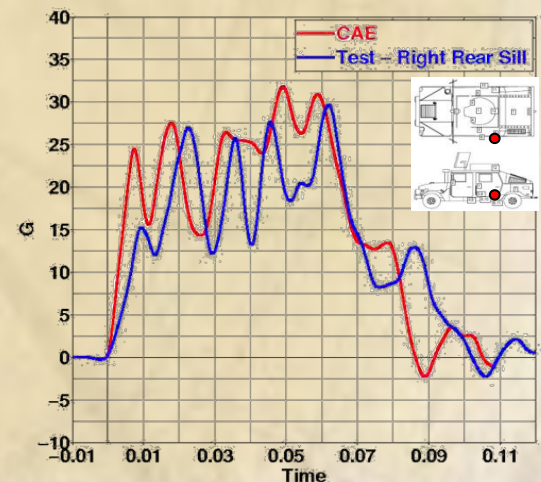
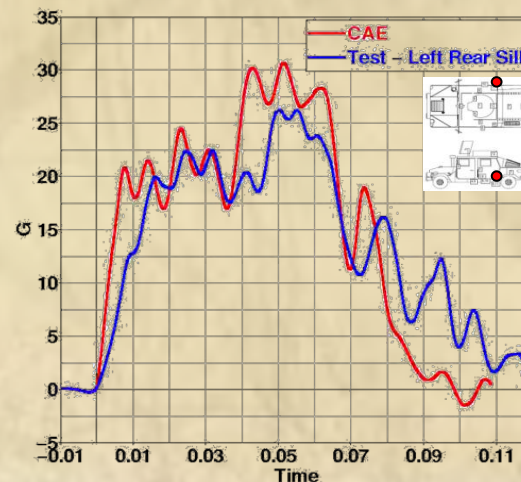
**Determine occupant injury using computational and physical instrumented test devices**



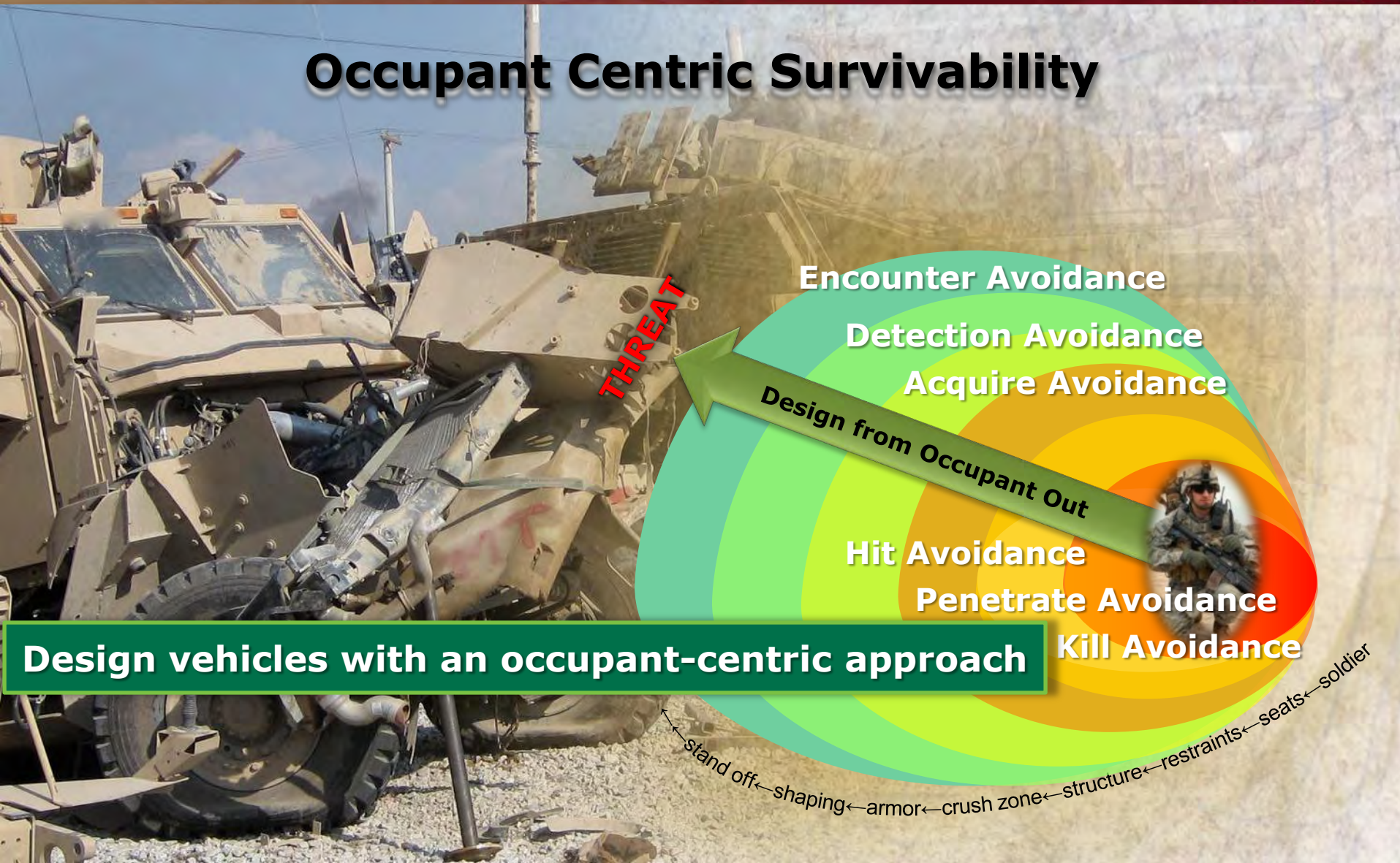


## TARDEC is uniquely situated to leverage:

- ❑ Decades of crashworthiness and Safety R&D
- ❑ Large local Safety community and resources
- ❑ Mature M&S tools and best practices
- ❑ Skilled personnel



## Occupant Centric Survivability



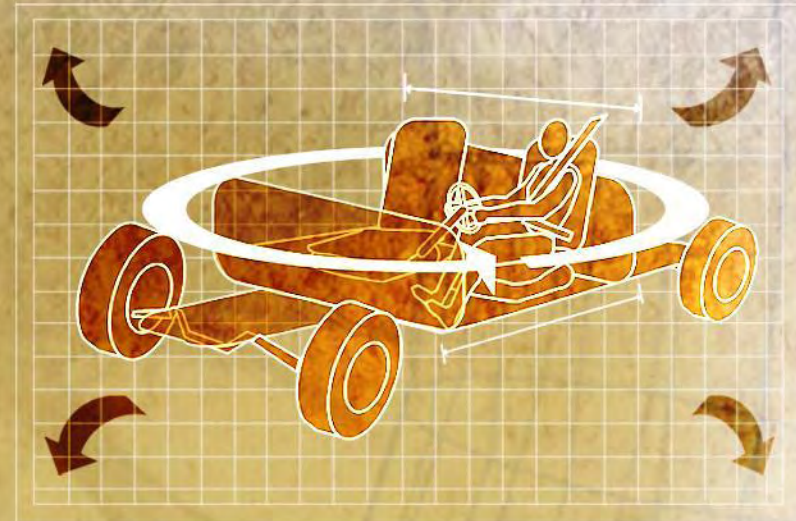
**Design vehicles with an occupant-centric approach**

# Designing from the Inside Out

~~Outside In~~



Inside Out



**Occupant Protection  
Drives Vehicle Design**



# End-to-End Underbody Blast Simulation

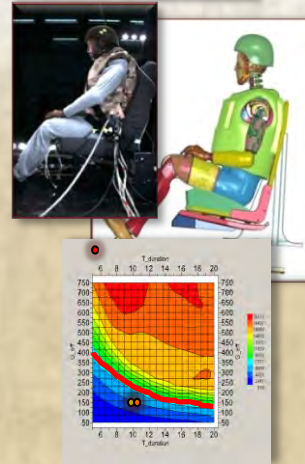
Energetic Event  
(UB Blast)



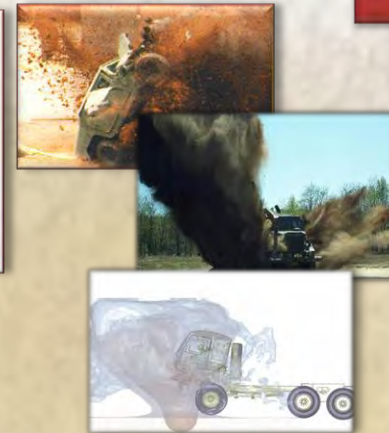
Component & Platform  
Interaction



Occupant Injury  
Response



System  
Evaluation



Design  
Improvement &  
Optimization



Current capabilities:  
Bare surface/buried  
charge (TNT/C4),  
soil, soil/charge  
coupling

Current capabilities:  
Structural analysis of  
vehicle hull/sub-  
systems/ EA  
technologies/seat/  
restraint designs

Current capabilities:  
Mechanical  
response of Hybrid  
III ATD with PPE to  
accelerative loading  
to assess occupant  
survivability

Current capabilities:  
Full vehicle, system  
level simulation from  
charge to occupant  
in a single  
computational run

Current capabilities:  
Design changes  
evaluated to  
understand overall  
system level effects  
for trends.

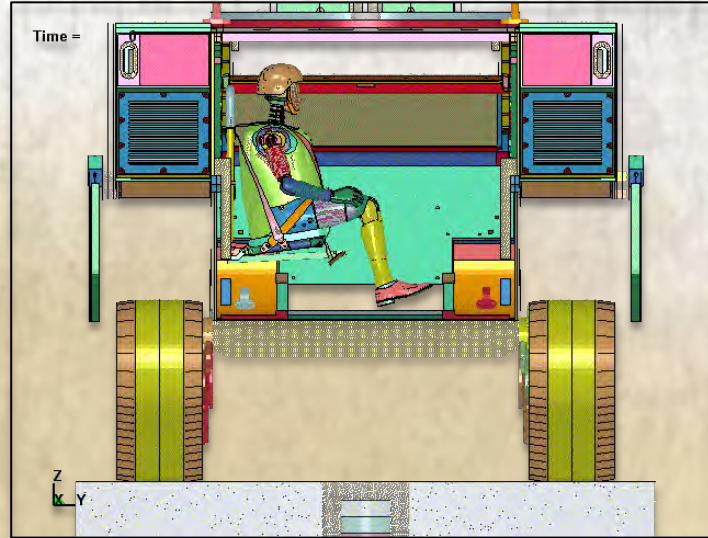
**Provide design evaluations, analysis, validation, and optimization of structure and crew response during underbody blast threats**



# Essential Elements of End-to-End Blast Simulation



Advanced Reconfigurable Spaceframe (AReS): TARDEC Demonstrator

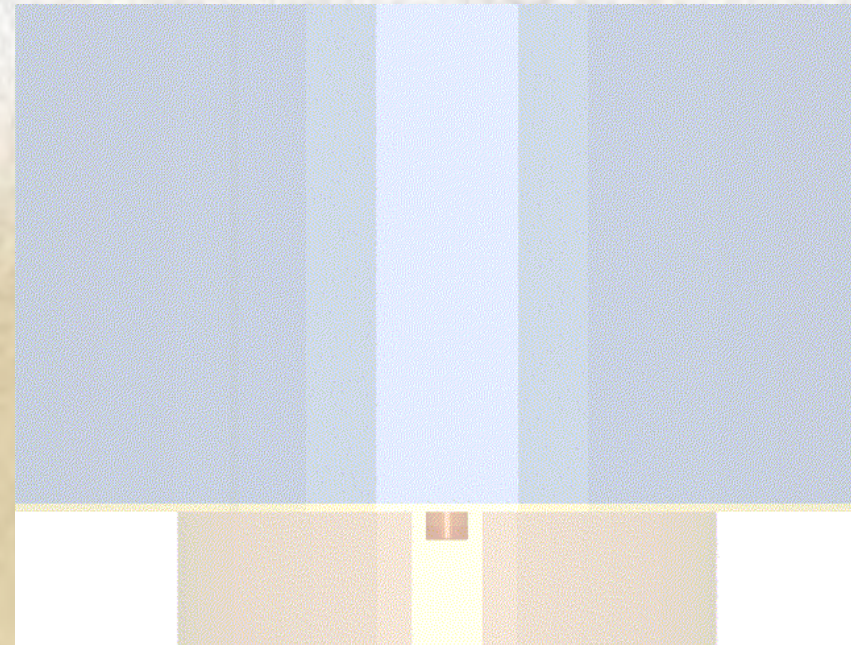
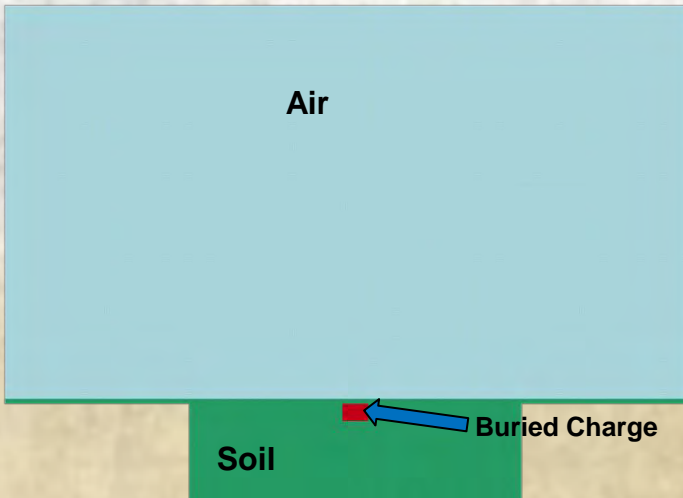


End-to-End M&S of AReS system

One single computational run is used to assess system level effects for underbody blast events

Following slides will show the essential steps in this process....

# Step#1: Modeling of explosive and soil



Explosive (JWL High Explosive):

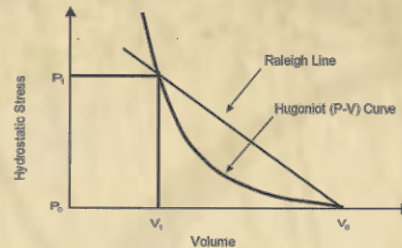
$$p = A \left( 1 - \frac{\omega}{R_1 V} \right) e^{-R_1 V} + B \left( 1 - \frac{\omega}{R_2 V} \right) e^{-R_2 V} + \frac{\omega E}{V}$$

Soil (Gruneisen):

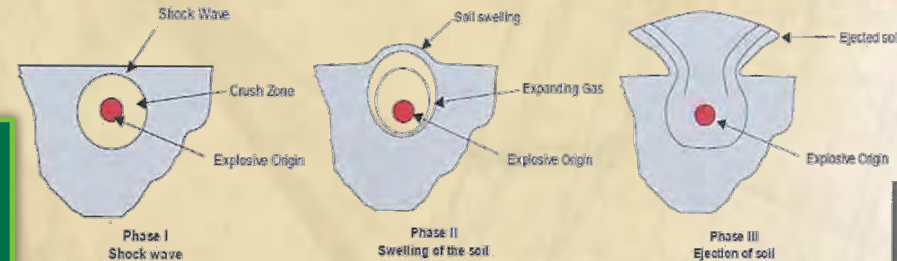
$$p = \frac{\rho_0 C^2 \mu \left[ 1 + \left( 1 - \frac{\gamma_0}{2} \right) \mu - \frac{a}{2} \mu^2 \right]}{\left[ 1 - (S_1 - 1) \mu - S_2 \frac{\mu^2}{\mu + 1} - S_3 \frac{\mu^3}{(\mu + 1)^2} \right]} + (\gamma_0 + \alpha \mu) E$$

AIR (Linear Polynomial):

$$p = C_0 + C_1 \mu + C_2 \mu^2 + C_3 \mu^3 + (C_4 + C_5 \mu + C_6 \mu^2) E$$

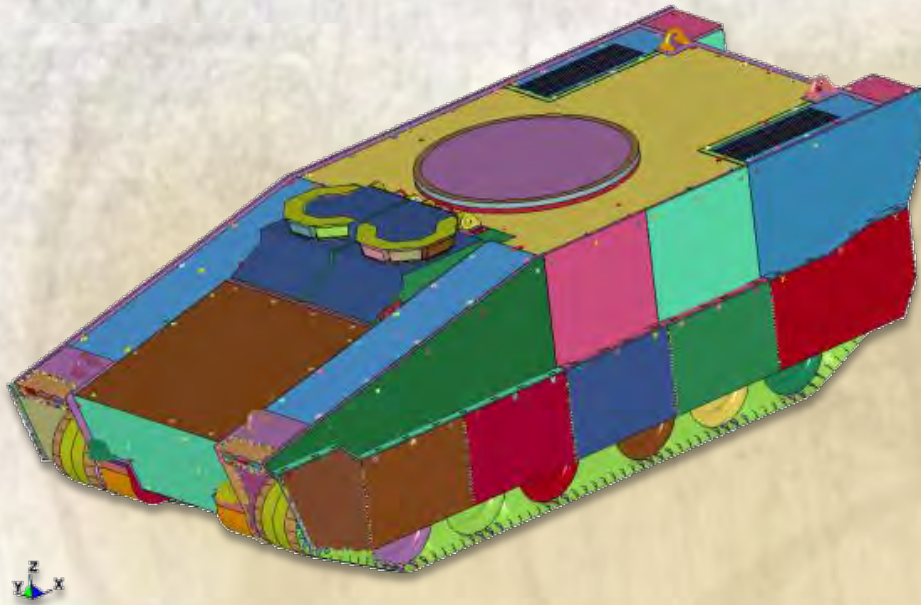


**Inputs from  
ARL testing  
and R&D feed  
this phase**



**Charge characteristics and Soil containment fully defined (Eulerian)**

## Step#2: Modeling of target vehicle

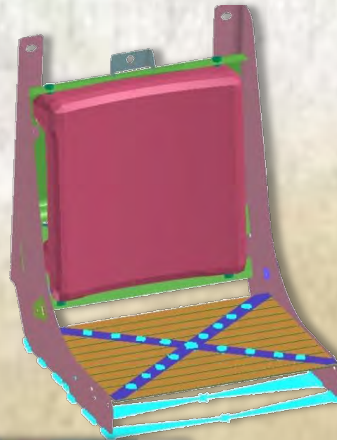


Target vehicle model includes:

- All structural hull components
- Underbody armor/kits and other Armor
- Suspension, wheels, tracks
- Other non-structural weights
- Materials modeled using nonlinear high strain rate properties such as Johnson-Cook available from ARL, Academia, National labs etc.

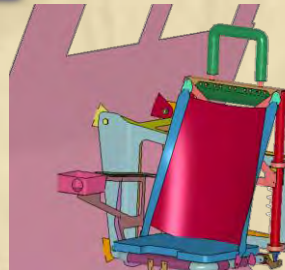
**Target vehicle fully defined by Finite Element Model (Lagrangian)**

## Step #3: Modeling of seats and restraints



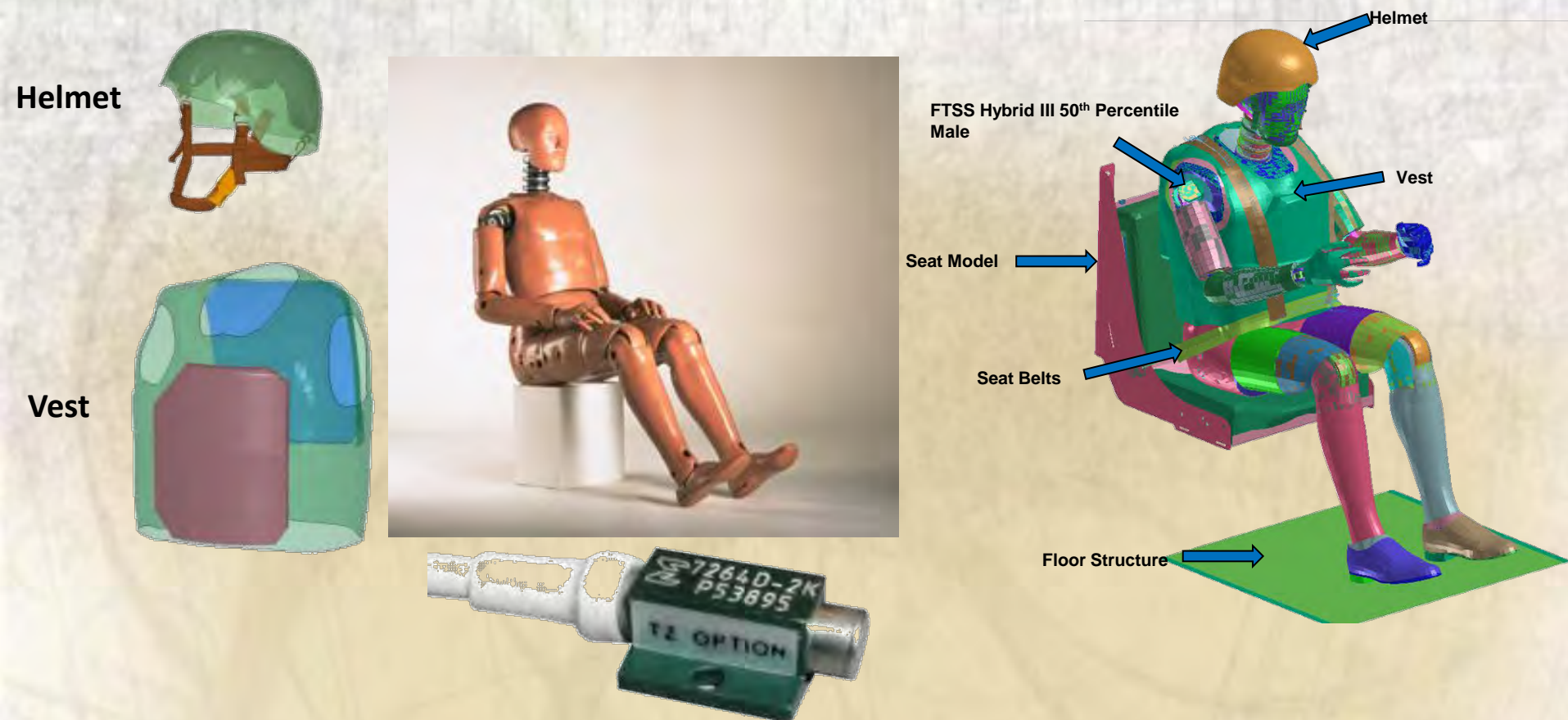
### Seat models include:

- All structural frame parts
- Seat belts and other restraints
- Energy Attenuating (EA) features that make up the Mine Blast seat
- Seat cushions and other comfort features
- Materials modeled using nonlinear high strain rate properties such as Johnson-Cook available from ARL, Academia, National labs etc
- Seat Characterization data from ARL



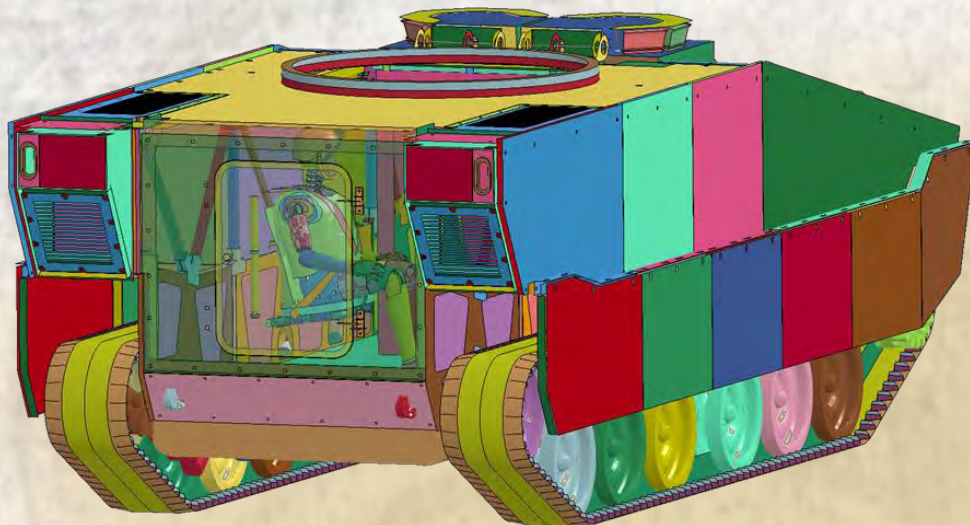
**Seats and Restraints fully modeled including Mine Blast features**

# Step #4: Modeling of occupants and PPE

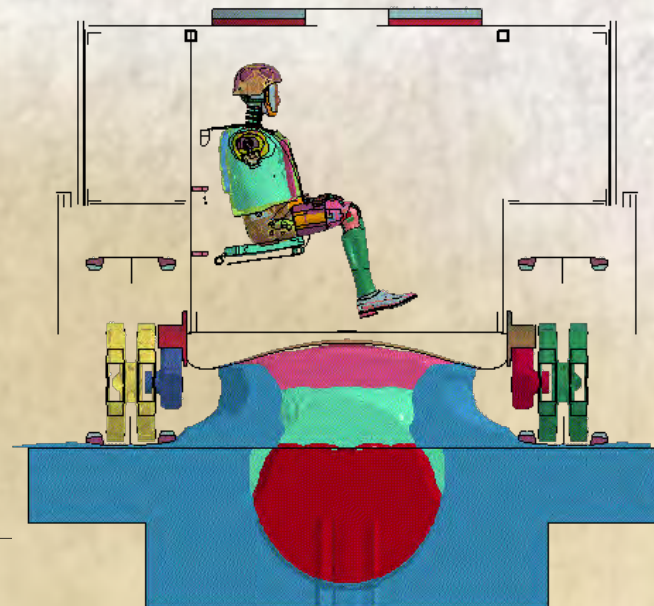


**FEA model of 50<sup>th</sup>-percentile HYBRID-3 Anthropomorphic Test Dummy (ATD) w/Sensors and PPE used in M&S**

# Step #5: Integration and Interface Modeling



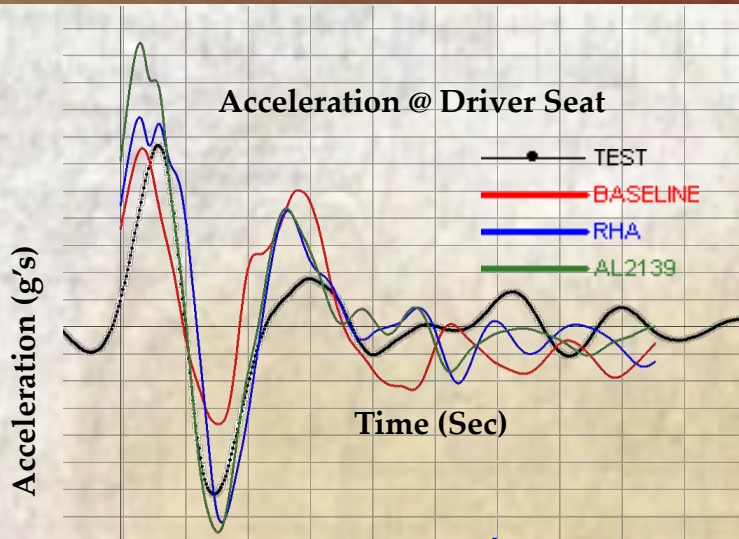
**M&S Model: System Integration**



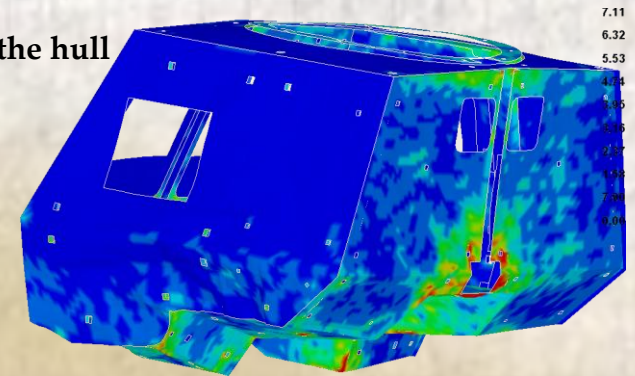
**Fluid Structure Interface (FSI)  
between the explosion  
products and the vehicle in  
Arbitrary-Lagrangian Eulerian  
(ALE) setup**

**Transfer of shock from mine explosion to the vehicle and occupant**

# Outputs from End-to-End M&S: Structural Integrity

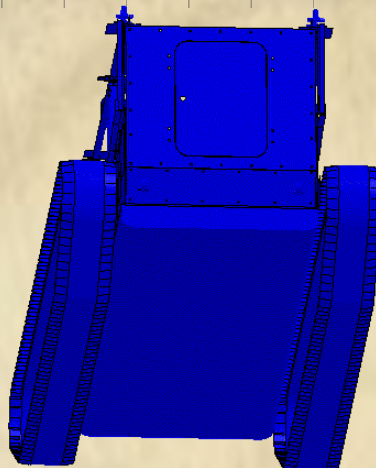


Strain contours in the hull

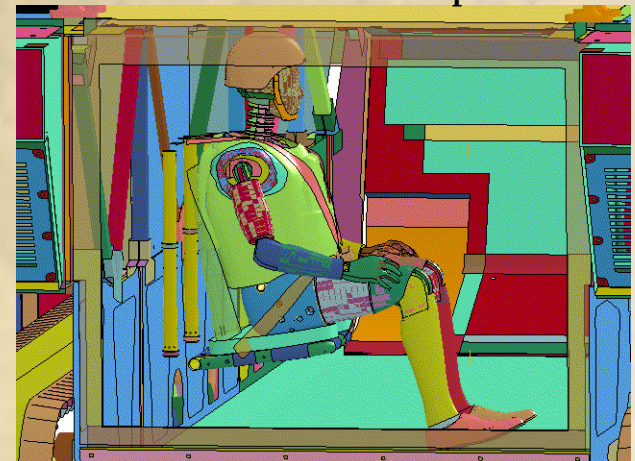


These results  
feed into  
Reduced Order  
Models

Shock pressure wave  
transmission on the  
underbody



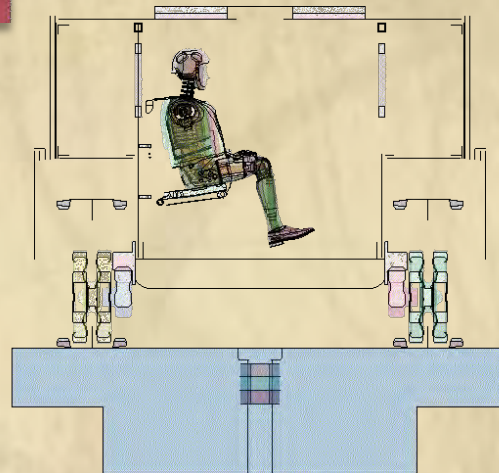
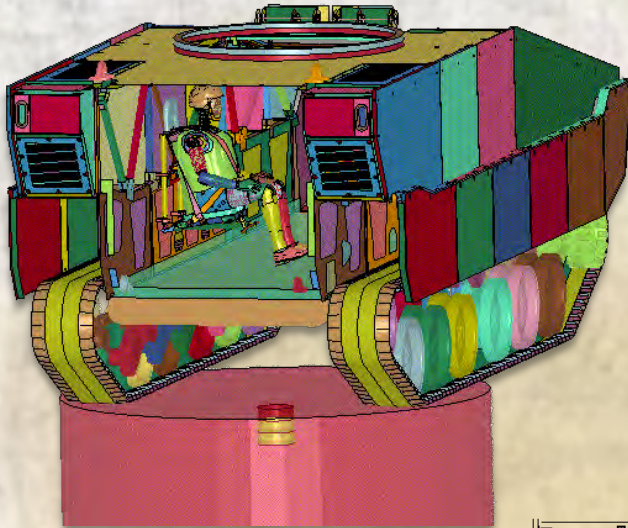
Seat Stroking to mitigate blast  
effect on occupant



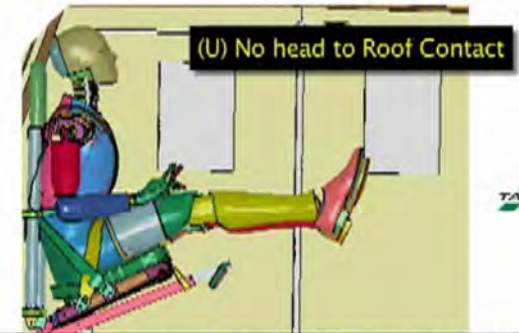
Evaluation of Structural Integrity is key to designing survivable ground vehicles

# Outputs from End-to-End M&S: Occupant Response

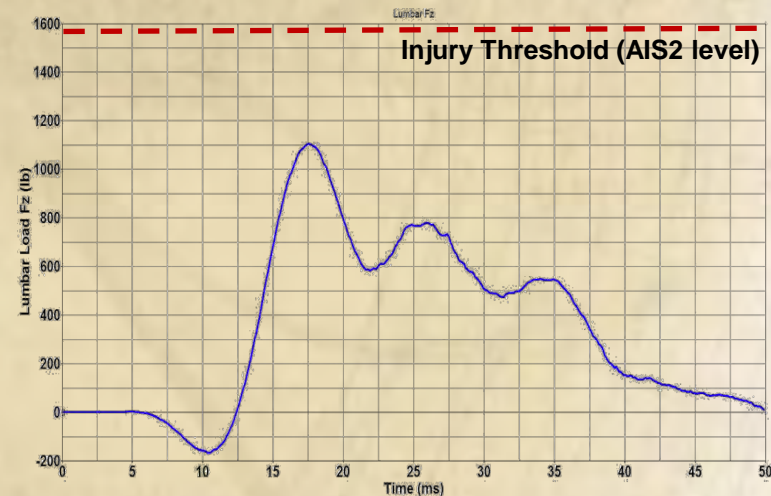
Time = 0



## (U) Belted Occupant



(U) Probability of head fracture risk is MINIMAL  
(U) Probability of spinal fracture risk is MINIMAL



**Occupant kinematics and Injury parameters are key deliverables**

# Related Efforts: Data Capture and Sharing



TARDEC CTC Vehicle Data Recorder System (Black Box)

## Blast/IED Event Data Recorder System

- Addresses gaps that exist in theater data collection
- Directly supports:
  - Development of test procedures and resultant countermeasures to protect the Warfighter
  - Accident and combat event investigations
  - Understanding of injury mechanisms within operational context
  - Full understanding of the event, so that countermeasures can be optimally designed and integrated



Tri-axial accelerometer, angular rate and pressure sensor



## Generic Hull Testing

- TARDEC, USAARL and USARL partnered with industry and academia to conduct a live fire blast test on a generic vehicle hull
- The data from this test is unclassified, and releasable to industry and academia (POC: [Risa.Scherer@us.army.mil](mailto:Risa.Scherer@us.army.mil) )
- Enable better understanding of the dynamics of underbody mine blasts that will seed the growth of new and innovative technologies



**Enables critical data collection in test and theater events**



Unclassified: DIST A. Approved for Public Release

# End-to-end M&S for Underbody Blast: Application of Systems Engineering



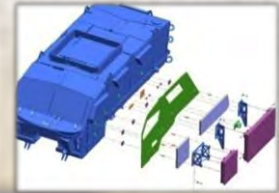
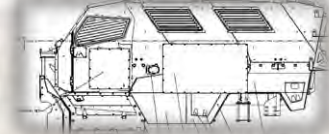
Bridge between  
Users & Technology  
Developers

Performing Key  
Analysis

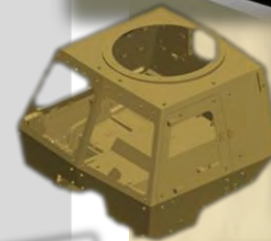
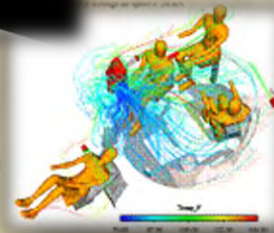
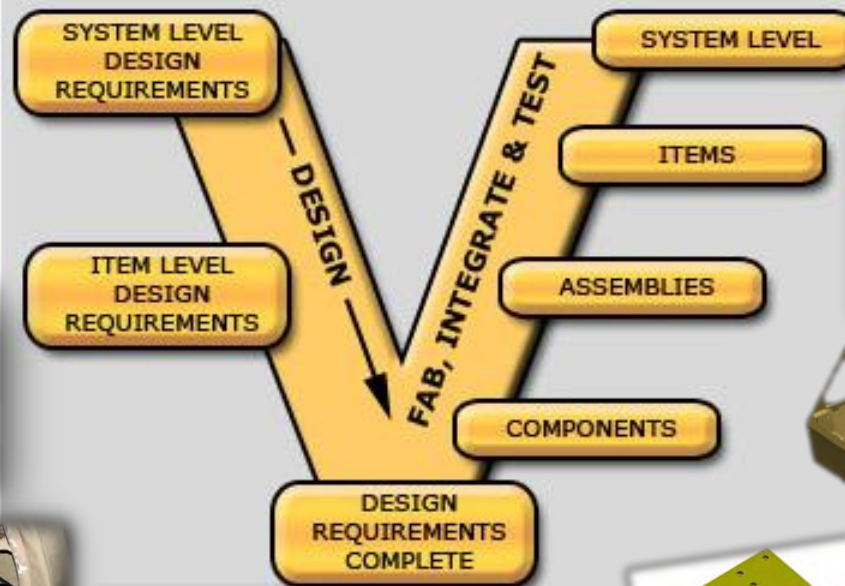
Shaping Trade Space

Concept  
Development and  
Evaluation

Joint and Service  
Specific



Source: Defense Acquisition University



**End-to-end Blast Modeling is critical part of Systems Engineering to  
Develop, integrate, sustain technology solutions for Warfighter**

## Summary

- **The underbody blast event is a very complex and highly transient phenomenon – very short duration and extremely high G values.**
- **Blast modeling and simulation tools, processes and best practices are leveraged from the automotive industry to assess blast survivability vehicle performance.**
- **Occupant injury risk assessment tools and injury metrics for underbody blast events are based off of automotive standards and need further investigation / validation.**
- **Current M&S tools are beneficial for guiding the vehicle design and development process, and are being evaluated for supporting Test & Evaluation.**
- **Advanced full vehicle, system level design tools are key enablers to:**
  - **Assessing Occupant Injury Risk**
  - **Developing new protection technologies**
  - **Improving current force vehicles for current threats**
  - **Designing new vehicles from the “Inside Out” (occupant-centric)**

## End-to-end System level M&S tool for Underbody Blast Events



**This brief will start again shortly.....**